GLAZING INSPECTION

This invention relates to novel method of forming a shadowgraph which is used in a method for determining the optical quality of glazings, in particular vehicle glazings.

In the production of vehicle glazings it is desirable to inspect every glazing to determine its optical quality, to ensure that it is acceptable for use as a vehicle glazing.

The use of shadowgraphs for evaluating the optical quality of glazings is well known. A glazing is positioned between a localised light source (a high intensity point source) and a shadowgraphic image of the glazing is projected onto a screen. The shadowgraph image is recorded by a CCD camera and analysed with the aid of a computer. The shadowgraph of a glazing is characterised by illumination variations which are related to the transmitted distortion of the glazing. The transmitted distortion of a glazing is caused by variations in the thickness of the glass. In the case of a laminated glazing these variations can be introduced during the manufacture of the glass plies, or may be introduced during the lamination process. The result is an effect called "wedge". Ideally, the faces of the glass plies are perfectly parallel so that after lamination the plies are retained parallel to each other. In practice, however, there are variations in the thickness of the individual glass plies and the laminate itself that produce shallow wedge shaped sections in the glass or laminated glazing which causes deflection of light resulting in optical distortion. Variation in this wedge angle causes transmitted light to converge or diverge and this is represented in the shadowgraph image by illumination variations. The more rapidly the wedge angle changes across the surface of the glass, the greater this convergence or divergence becomes.

US 5694479 discloses a process for measuring the optical quality of a glazing which utilises shadowgraphs. A shadowgraph image of the glazing is projected onto a screen and is recorded and processed such that point measurements are made of the illumination. The processed shadowgraph image is then used to construct a reference image and comparisons are then made between points of the processed image and corresponding points of the reference image. In constructing the reference image, it is first necessary to determine an illumination value for all measurement points of the recorded shadowgraph image, including the regions of the image corresponding to printed areas of the glazing. In these regions an illumination value is estimated by extrapolating from the

known illumination values of adjacent measurement points. Once illumination values
have been estimated for the measurement points on the shadowgraph image
corresponding to the printed areas of the glazing, the reference image is constructed by
carrying out convolution filtering over the entire shadowgraph image. Constructing the
reference image in this way is time consuming and a number of calculations are carried
out which are unnecessary. In addition, dark room conditions are required to form the
shadowgraph.

It is an object of the present invention to improve on the aforementioned process.

According to an embodiment of the invention there is provided a method of
forming a shadowgraph image of an object comprising forming the image as a virtual
image on a virtual image plane. Such a method can be used in ambient light conditions
and dark room conditions are not required as they would be with conventional
shadowgraph methods where the shadowgraph image is formed on a screen.

The shadowgraph image may be formed by illuminating the object with a
collimated light beam from a localised light source to create a shadowgraph image on the
virtual image plane.

The virtual image plane may be positioned behind or in front of the object.

Preferably a wedge prism is used to tilt the virtual image plane. This is particularly
useful when measuring the transmitted distortion of objects when it is required or
desirable to make measurements at an angle, for example windscreens.

The light source is preferably an LED. An LED (light emitting diode) is
particularly suitable because it is a very small point source and consequently it improves
the spatial resolution of the system over light sources used in the production of
conventional shadowgraphs (e.g. arc lamps). In addition, an LED is a solid state
component and has a long life.

The light may be collimated by a lens optical system or a mirror optical system.
The use of a mirror system has advantages over a lens system in that it is cost effective
and more compact with reduced spherical aberration in comparison with a lens system.

The object is preferably a glazing.

The invention also provides a method of determining the optical quality of a
glazing which includes at least one area having a reduced light transmission comprising
the following steps:

producing a shadowgraph image of the glazing as claimed in any of claims 1 to 9;

measuring the illumination of the glazing at a plurality of measurement points arranged in an array extending over the glazing;

determining any deviation in illumination at those points from a desired value at each point;

wherein the at least one area of reduced light transmission is omitted from the array of measurement points.

The invention further provides a method to determine the optical quality of a glazing comprising the following steps:

illuminating the glazing with a localized light source to produce a shadowgraph image as claimed in any of claims 1 to 9;

recording the shadowgraph image;

determining valid measurement points of the shadowgraph image which excludes those points which correspond to obscured areas of the glazing;

processing the recorded shadowgraph image to determine an illumination value for each valid measurement point;

constructing a reference image by scanning a convolution window point by point over the processed image and using a convolution filter to calculate a reference illumination value at points of the reference image which correspond to each point of the processed image by averaging the illumination values of the valid measurement points of the processed image covered by the convolution window;

comparing the illumination value of each valid measurement point of the processed shadowgraph image with corresponding points of the reference image to determine the optical quality of the glazing.

The optical quality of the glazing is ignored in the areas in which it is obscured (e.g. a printed peripheral obscuration band, or a printed patch which conceals the base of a rear view mirror attached by adhesive), and hence the method of processing the shadowgraph image only performs calculations which are necessary and reduces the amount of time required to determine the optical quality of the glazing.

In a preferred embodiment of the invention the convolution window is of constant area during the scanning operation.

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The method preferably includes the step of recording the reference image for comparison with the processed image.

In the method a valid measurement point is preferably one in which the illumination value at that point is equal to or above a pre-set threshold.

In the method it is preferable that when the point of the convolution window for which the reference illumination is being calculated corresponds with a non-valid measurement point of the processed image, a reference illumination is not calculated.

In a preferred embodiment non-valid measurement points are not taken into account in the construction on the reference image.

Preferably the same light source is used for the production of the shadowgraph image and in relation to calculating the reference image.

Embodiments of the invention will now be described with reference to the drawings in which:-

Figure 1 is a schematic perspective view of the arrangement of apparatus for producing a shadowgraph as a real image on a screen.

Figure 2 is a schematic side view of apparatus for producing a shadowgraph as a virtual image on a virtual plane.

Figure 3 is a top view of Figure 2.

Figure 4 is a side view of a mirror optical system which may be used in the method of the invention.

Figure 5 is a top view of Figure 4.

Figures 6A-6D show different positions of a convolution window as it scans part of a glazing in a method to construct a reference image used in the determination of the optical quality of the glazing.

Figures 7A-7C show different positions of a convolution window as it scans part of a glazing in an alternative method to construct a reference image used in the determination of the optical quality of the glazing.

Figure 1 illustrates the formation of a shadowgraph image as a real image on a screen. A localised light source 10 illuminates a windscreen 12 and produces a shadowgraph image 14 of the windscreen on screen 16. A printed patch 30 on the windscreen is shown which conceals the base of a rear view mirror attached to the windscreen with an adhesive. This patch casts a shadow 32 on the shadowgraph image

14. The light source is a 450W Xenon arc lamp which provides a high intensity point source. The distance between the light source 10 and the windscreen 12 is 4m and the distance between the windscreen 12 and the screen 16 is 2m. In the case of windscreens it is preferable that the measurements are carried out under real conditions, and so the windscreen is observed at an angle similar to what it would be when fitted in a vehicle and the axis of the light source is horizontal and parallel to the axis of the vehicle. A CCD camera 18, for example a 10 bit areascan CCD camera with linear response such as Hitachi camera model number KP-F1, is also shown which records the shadowgraph image 14. Whilst the camera 18 is shown in Figure 1 to be below the windscreen 12, this is not essential. It is only necessary that the camera has a non distorted view of screen 16 so that it can record the shadowgraph image 14. The CCD camera 18 is associated with a computer 20 which is used in determining the optical quality of the glazing. The shadowgraph image 14 recorded by the camera 18 is stored in the memory of computer 20 to aid in the construction of the reference image, and also for comparison with the reference image.

Figures 2 to 5 relate to the formation of a shadowgraph image as a virtual image in a virtual image plane. In Figure 2 a localised light 50 source is expanded and collimated by lens 54 to illuminate windscreen 52. A "virtual" shadowgraph image is created on a virtual image plane 56 in space behind the windscreen. It will be appreciated that whilst the virtual image plane 56 is shown in this example to be positioned behind the windscreen 52, it could be arranged to be positioned in front of the windscreen. Lenses 58 and 60 enable both collection of the expanded collimated light and focussing of CCD camera 62 onto the virtual image plane. The distance between the light souce 50 and the windscreen 52 is about 2m and the distance between the windscreen 52 and the camera is about 2m. In this particular example the virtual image plane is approximately 1m from the windscreen, but this can be varied.

The CCD camera 62 is a linescan camera which is used to sample the light intensity of the virtual shadowgraph image along the direction of the linescan elements, which is recorded in computer 64. A suitable CCD camera for this application is the Aviiva camera (4K pixels; 10μm pixel) available from Atmel Corporation.

A linescan camera is used because the windscreen (and hence the virtual image plane) is moving in the direction shown by arrow 70 in Figure 3, which enables the

linescan camera to scan the entire virtual shadowgraph image by making a plurality of line scans. Each linescan is recorded in computer 64 and combined in such a way (built up from a series of single pixel lines) that the computer holds a record of the virtual shadowgraph image of the entire windscreen.

It will be appreciated that appropriate positioning of the camera may be advantageous. Light from source 50 is directed towards camera 62 with the windscreen and virtual image plane being located in the light path between the source and the camera. With this arrangement almost all the light transmitted through the windscreen is sensed by the camera. This means that the system can be used in ambient light conditions and dark room conditions are not required as they would be with conventional shadowgraph systems where the shadowgraph image is formed on a screen. Also, a lower power light source may be used than is needed in conventional shadowgraph systems. A light emitting diode (LED) is particularly suitable because it is a very small point source and consequently it improves the spatial resolution of the system over light sources used in the production of conventional shadowgraphs (e.g. arc lamps). In addition, an LED is a solid state component and has a long life. A slit 67 about 10mm wide may advantageously be used to reduce ambient light reaching the camera's sensing elements, thereby increasing the sensitivity of the system.

Advantageously a wedge prism 66 may be provided between lens 60 and CCD camera 62 to tilt the virtual image plane. This is particularly useful when measuring the transmitted distortion of objects when it is required or desirable to make measurements at an angle, for example windscreens where it is preferable that the measurements are carried out under real conditions, so the windscreen is observed at an angle similar to what it would be when fitted in a vehicle and the axis of the light source is horizontal and parallel to the axis of the vehicle.

As an alternative to using a lens optical system to focus the light transmitted from source 50 through the windscreen 52 onto a virtual image plane 56, a mirror optical system can be used. Such a system is illustrated in Figures 4 and 5 with light from source 50 being reflected from plane mirror 72 and concave mirror 74 towards virtual image plane 56. Similarly a mirror system could be used to collect the collimated light. The use of a mirror system has the advantages of being cost effective and more compact with reduced spherical aberration in comparison with a lens system.

The virtual shadowgraph image recorded by computer 64 is processed by the computer in the same way as the real shadowgraph image is processed in our co-pending UK application number 0306259.3. Computer 64 detects valid and non-valid measurement points, where a valid measurement point corresponds to a non obscured part of the glazing and a non-valid measurement point corresponds to an obscured part of the glazing (e.g. a printed peripheral obscuration band, or a printed patch which conceals the base of a rear view mirror attached by adhesive). The valid measurement points are detected by the computer where the illumination value at that point is equal to or above a pre-set threshold and the non-valid measurement points are detected where the illumination value at that point is below the pre-set threshold. The shadowgraph image is then processed by quantifying the illumination values for each valid measurement point which is then stored in the computer memory. For each non-valid measurement point the illumination value is not quantified, but simply given a value of zero which is stored in the computer memory.

The processed image therefore consists of quantified point measurements of the illumination value of the recorded shadowgraph image for all measurement points except those points which correspond to obscured or printed areas of the glazing (i.e. the processed image comprises quantified point measurements of the illumination value of the valid measurement points). It is this processed image which is used to construct the reference image. This is done by "smoothing" the processed image by convolution filtering - scanning a convolution window point by point over the processed image and for each valid measurement point of the processed image a corresponding reference illumination value is calculated for the reference image by averaging the illumination values of the valid measurement points of the processed image covered by the convolution window.

Construction of the reference image by convolution filtering is straightforward in areas of the glazing in which the convolution window covers only valid measurement points of the processed image. However, where the convolution window covers at least one non-valid measurement point, adjustments need to be made.

Preferably a convolution window of dimensions 31 x 31 measurement points is used, but for illustrative purposes and with reference to Figure 6, one of 3 x 3 measurement points will be used. Figure 6, which is not to scale, shows part of the

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processed image which includes valid and non-valid measurement points shown as a grid, each measurement point being represented as a box. The convolution window is depicted by the boxes within the boundary marked 28 (of 3 x 3 boxes). The non-valid measurement points are shown as a solid block 32 and in this particular instance correspond to a printed patch 30 on the glazing which conceals the base of a rear view mirror attached to the windscreen with an adhesive. A convolution window 28 is shown at four successive positions during its scanning over the processed image, position 1 at Figure 6A, position 2 at Figure 6B, position 3 at Figure 6C and position 4 at Figure 6D. At each position during its scanning over the processed image, the arithmetic mean of the illumination values of the valid measurement points, is carried out. In Figure 6 the dimensions of the convolution window is 3 x 3 and it is the geometric centre point of the window (shown as box 5) for which the reference illumination is being calculated.

In position 1 as shown in Figure 6A the convolution filtering is straightforward as the convolution window covers only valid measurement points. To obtain the reference illumination value for the point of the reference image corresponding to the point of the processed image covered by box 5 of the convolution window, the following calculation is performed:

$$I_5 = \left[\sum_{9}^{1} I\right] /9$$

i.e. the average of the actual illumination values of boxes 1 to 9 of the convolution window, each of which correspond to valid measurement points of the processed image.

In position 2 as shown in Figure 6B, the convolution window covers one non-valid measurement point of the processed image (corresponding to the point covered by box 9 of the convolution window). This point is ignored in calculating the reference illumination value for the point of the reference image corresponding to the point covered by box 5 of the convolution window, and the following calculation is performed to obtain the reference illumination value at that point:-

$$I_5 = \left[\sum_{8}^{1} I\right] /8$$

i.e. the average of the actual illumination values of the boxes 1 to 8 of the convolution window, which correspond to valid measurement points of the processed image.

In position 3 as shown in Figure 6C, the convolution window covers two non-valid measurement points of the processed image (corresponding to the points covered by boxes 8 and 9 of the convolution window) and these points are ignored in calculating the reference illumination value for the point of the reference image corresponding to the point covered by box 5 of the convolution window, and the following calculation is performed to obtain the reference illumination value at that point:-

$$I_5 = \left[\sum_{7}^{1} I \right] / 7$$

i.e. the average of the actual illumination values of boxes 1 to 7 of the convolution window, which correspond to valid measurement points of the processed image.

In the case where box 5 of the convolution window covers a non-valid measurement point of the processed image, such as the position shown in Figure 6D, no reference illumination value is calculated and the corresponding point of the reference image is given a value of zero.

By performing convolution filtering as described above over the entire surface of the processed image, a reference image is constructed which comprises a reference illumination value for each corresponding valid measurement point of the processed image.

The reference image is now compared with the processed image to determine the optical quality of the glazing. The comparison is carried out by comparing the illumination values of corresponding points and calculating the ratio of illumination values of the points of the processed image to those of the reference image. In this way it is possible to determine defects in the glazing which can be compared with a specification, usually one provided by the vehicle manufacturer, to determine whether or not the glazing meets the required specification.

In the above method described with reference to Figure 6, the convolution window effectively reduces in size when calculating a reference illumination value when the window scans over at least one non-valid measurement point of the processed image. For

example in Figure 6A the area is 9 boxes, in 2B it is effectively 8 boxes and in Figure 6C it is effectively 7 boxes. This is because when the window covers boxes which correspond to non-valid measurement points of the processed image, these boxes are not taken into account in calculating the reference illumination value. In an alternative method, the convolution window may have a constant area during the scanning operation throughout entire construction of the reference image, i.e. when it scans over valid measurement points only of the processed image and also when it scans over non-valid measurement points of the processed image. This is done by altering the shape of the convolution window so that when it does cover a non-valid measurement point of the processed image, that non valid measurement point is ignored and replaced by a valid measurement point adjacent to the convolution window. In such a method the point of the convolution window at which the reference illumination is to be calculated may not always be the geometric centre point of the window, but is a pre-determined point of the convolution window. This method is illustrated in Figure 7, and in this particular example box 5 has been selected as the point of the convolution window at which the reference illumination is to be calculated, although a different box could be selected. The reference illumination calculated by this method for the point of the reference image corresponding to the point of the processed image covered by box 5 in each of the positions shown in Figures 7A-C is :-

$$I_5 = \left[\sum_{9}^{1} I\right] / 9$$

In each example illustrated in Figure 7, the area of the convolution window is 9 boxes although in each case the window is not a 3x3 square of boxes.

As before with reference to the method described with reference to Figure 6, a reference image is constructed by performing convolution filtering over the entire surface of the processed image, and the reference image comprises a reference illumination value for each corresponding valid measurement point of the processed image. The reference image is now, as before with reference to the method described with reference to Figure 6, compared with the processed image to determine the optical quality of the glazing by comparing the illumination values of corresponding points and calculating the ratio of

illumination values of the points of the processed image to those of the reference image. The defects in the glazing are thus determined and compared with a specification, usually one provided by the vehicle manufacturer, to determine whether or not the glazing meets the required specification.

In the above methods the same light source is used for the production of the shadowgraph image and in relation to calculating the reference image. This reduces errors which may be generated if different light sources are used

It will be appreciated that the dimensions of each measurement point are smaller than the areas of the glazing which have a reduced light transmission, e.g. the printed patch 30 or a peripheral obscuration band. In the foregoing embodiments each measurement point has the dimensions of a pixel of the shadowgraph image which corresponds to a single sensing element of the CCD camera.

With reference to the example described with reference to Figures 2 to 5, it will be appreciated that the windscreen 52 (and hence the virtual image plane) moves relative to the camera 62, which has the advantage that the system can be operated on a production line. However, it is possible that the glazing under test (and hence the virtual image plane) remains stationary in which case an areascan camera may be used to record the shadowgraph.

It will also be appreciated that the system may be used to measure the transmitted distortion and/or surface imhomogeneities of objects other than glazings, such as spectacle lenses, contact lenses or mirrors. A linescan camera may be used provided there relative movement between the object under test and the camera, or an areascan camera could be used if there is no such relative movement.